

A REVIEW ON MINIMUM QUANTITY LUBRICATION (MQL) FOR SUSTAINABLE MACHINING PROCESSES AND ITS APPLICATION

RAHUL D JADHAV & Dr. RAJESH KUMAR BHUYAN

*Department of Mechanical Engineering, Koneru Lakshmaiah Education Foundation, Vaddeswaram ,
Andhra Pradesh, India*

ABSTRACT

The use of cutting fluid by industrial manufacturers has benefited the machining processes, effectively. Cutting fluids reduce the temperature of the surface, frictional effects; it also removes chips by flushing them and therefore extends tool lifespan by improving machining performance. However, the consumption of excess amount of cutting liquid arises concern in regard to production rate and ecological problem. Therefore, a common target of manufactures is to develop a safer working atmosphere and reduce production cost by drastically reducing the use of cutting fluid in machining. The feasible solution to achieve this goal is minimum quantity lubrication (MQL), in which we deliver the lubricant at very small flow rate to machining zone. MQL technique has evidence, as it is suitable to comply for the fulfillment of 'Green Machining'. Therefore, in this study, the effects of MQL in turning, drilling, grinding and milling application using mineral oils (base oils), vegetable oils (synthetic oils), and Nano-fluids on various materials are discussed.

KEYWORDS: *Cutting Fluid, Prolong Tool Life, MQL & Green Machining*

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INTRODUCTION

With the development of manufacturing science and technology, green manufacturing has become one of the main development directions of advanced manufacturing technology. When F. W. Taylor, in 20th century utilized water to cool the machining process for the first time and summarized that it has significantly improved tool life, a vast range of cutting fluids have been utilized with this and for other purposes. El Baradie [1] in his research findings classified cutting fluids in three main categories, i. e. water-soluble fluids, neat cutting oils and gases. The suitable uses of these cutting fluids are also discussed for various machining processes in his research work. However, in the last decade, various researchers have suggested reducing the utilization of cutting fluids in manufacturing, to reduce the cost of machining and to improve the healthiness of employees. Sreejith and Ngoi[2] presented the latest improvements in the dry machining operation and discussed about various other techniques to eradicate heat from the cutting region.

Weinert et al.[3] summarized that the practice of cutting fluids in machining operations directly influences the ecosystem and human health, both for the period of its use as well as after the disposal. To limit the utilization of cutting fluid in machining processes, two strategies have been tested intensively by the manufacturers: (I) cutting with no lubrication (dry cutting, otherwise called ecological machining) and (ii) cutting with a minimum quantity of lubrication (MQL), where a very low amount of oil flow (below 240 milliliter per hour), is used. Further said, machining oil is elevated to the actual machining zone with the help of compressed air, and thus the

oil + air mixture ensures less friction at the work piece-tool interface because of the excellent lubricating properties of the oil and cooling of the part provided by compressed air. Sharma et al. [4] conducted a review on MQL for manufacturing processes, tool wear, surface roughness, cutting force, temperature dissipation. MQL show noticeable progress in performance as compared with dry and flood lubrication. It is clear that minimum quantity lubrication not only helps to improve the ecological friendliness, but can also boost the machining performances. Chetan et al. [5] in their research finding, summarized of entirely the evolving sustainable manufacturing methods in machining for the green and cleaner manufacturing and categorized various sustainable methods in metal machining, with the purpose to make the machining process more economical and environment friendly. Now-a-days, among several machining techniques, the manufacturers and research scholars are more focusing on MQL due to its eco-friendly nature. The MQL technique is applicable to various machining process basically on grinding, turning, drilling and milling. As a blend of two machining, dry as well as wet, the MQL machining technique leagues the positive outcome of both techniques. The merits of MQL are evident in various fields likely as reducing the production costs, lawful demands and labor health. This paper summarizes the research progress of MQL (green machining technology) in the last two decades for the various machining processes. The major aim of this review paper is to first describe the MQL technology systematically, its requirements for cutting fluid are analyzed, and the role of cutting fluid in MQL cutting is discussed. In the next session, the work of various researchers is reported; the results or outcome of MQL using several types of Nano-lubricants and traditional cutting fluid is segregated based on various cutting operations (Turning, Drilling, Grinding and Milling).

MINIMUM QUANTITY LUBRICATION (MQL)

Astakhov [6] stated that minimum quantity lubrication (MQL), which is also referred as near-dry machining (NDM) is a procedure used to provide tiny particles of lubrication fluid to the machining region. A lesser amount of lubricating fluid is conveyed to the machining region supported by compressed air and transformed via orifices into tiny particles (atomization). These tiny particles are supplied to the machining region in the form of air borne particles, a gaseous suspension of liquid particles also known as aerosol. An idealized condition of MQL can be seen in below figure 1(a), in which a small oil particle is carried by the air in the atomized state and moves straight to the tool working region.

Classification of Minimum Quantity Lubrication System

In general, there are two types of MQL system. The first type is known as an internal system. In the internal system, oil and air is mixed in a mixing chamber before being delivered to the cutting zone through a single nozzle pipe.

Meanwhile, the second type, or external system, an oil-air mixture is carried out in the nozzle tip and the air borne particles are formed just after the nozzle tip. The oil is supplied in small quantities through a pipe to the nozzle tip where the air, flowing from a different pipe, will force the oil to the cutting zone. The difference between the external system (T-1) and internal system (T-2) is illustrated in below figure 1(b).



Figure 1(a): Idealized Concept of MQL.[6]

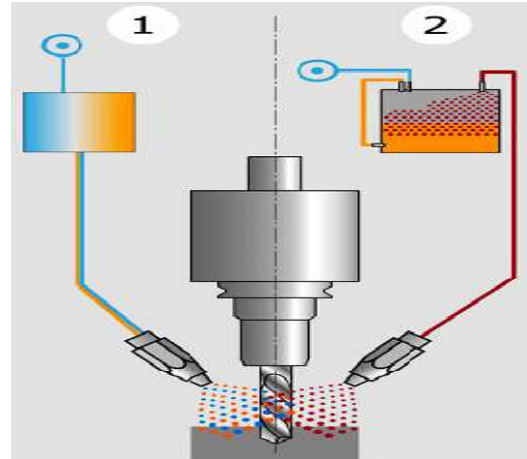


Figure 1(b): Types of MQL Feed Systems: 1 is External System; 2 is Internal System. [6]

Application of Minimum Quantity Lubrication (MQL) in Machining Processes

MQL method is very useful and can be utilized in many machining processes, most importantly in primary processes like turning, milling, drilling and grinding. Apart from that it can be utilized in cutting wide range of workpiece material, like steel, aluminum hardened material and hard-to-cut materials. Tawakoliet al.[7] found that the combination of MQL method with resin bond corundum can provide the good grinding operation in relationship to wet and dry machining. An acceptable surface integrity (roughness, residual stress, micro hardness and microstructures) in grinding processes can be achieved by proper utilization of MQL method. However, the use of MQL application in drilling processes which can be classified as closed-type processes have some limitations. The reason behind it is the struggle of air borne particles, which provides cooling and lubrication to the drill tip; usually during deep hole drilling. It can be overcome by providing internal cooling/lubricating channels which supplies coolant internally. It reduces the cutting temperature by almost 50% as compared to external coolant supply. Due to strict environmental policies and the increasing price of cutting fluid acquisition, the use of this conventionally used method is replaced to more eco-friendly processes like dry and near dry machining. MQL turning is one of the replacements for the environmental requirement.

MQL TECHNIQUE FOR VARIOUS MACHINING PARAMETERS

As stated in section 2.1, both types of MQL systems are affordable in terms of system and cost. Therefore, many MQL delivering systems have been made commercially available recently, in a wide variety of design and technology. The MQL equipment is normally installed on new and advanced technological machine tools. Therefore, the selection of the equipment's is dependent on the needs and investment cost constraints. To discover the advantages of the MQL technique in machining process, wide varieties of workpiece materials, comparison studies of MQL and flood cooling, as well as with dry machining, can be found in literatures. In this section, the review is focused on the various other parameters for different machining processes.

Minimum Quantity Lubrication Application in Turning Processes

Currently, researchers or industry R & D have strived to prove the effects of machining parameters on the efficacy of the MQL technique along process modelling and optimization. But, in the initial days of use of MQL in machining process, no noticeable difference were found with comparison to dry machining. Itoigawaet al.[8] in their experimental work performed a turning operation on aluminium alloy using CNC lathe machine. Synthetic esters (mono carboxylic acid

with polyalcohol) along with rapeseed oil were used as lubricants. In their findings, they have concluded that MQL with oil film on a water droplet offers decent lubrication if a suitable lubricant, such as synthetic ester, is used. Khan and Dhar[9] evaluated the performance parameters of MQL by implementing vegetable base oil in turning AISI-1060 steel. The outcomes of their work represents that the performance as well as dimensional accuracy is improved by the application of MQL in comparison to dry or plain cutting.

Khanet al.[10] extended their previous work and concluded that MQL made the finest surface finish over an extensive variety of machining time as compared with the wet machining and dry machining process. Hwang and Lee [11] observed that MQL technique for turning process is good as compared to wet turning. They also proposed the respective optimized arrangement of cutting parameters for turning with MQL to get better lubricating effect. Some of the researchers also studied MQL technique using Nano fluids. Rao and Satyanarayana[12] investigated the cutting tool nose wear and machining temperatures for the carbon nanotube mixed Nano fluid for MQL in turning operation. Cetin et al.[13] conducted a turning operation on AISI 304L using vegetable based cutting fluids to conclude that, the sunflower and canola as a based fluids execute superior machining than that of dry or wet operation.

Loharand Nanavaty[14] concluded in their findings, the use of MQL technique significantly affected various parameters, like 40% reduction in cutting force, 36% reduction in cutting temperature and 30% improvement in surface finish as equated to dry turning. Stephenson et al. [15] used supercritical CO₂- based MQL system to improve the tool lifecycle and boost the material removal or the production rate. They found that it significantly affected the parameter by 40% compared to aqueous fluid. Similar type of finding are achieved by Sainiet al. [16], who observed that using the MQL technique instead of dry machining the cutting forces reduced by 17.07% and cooling near tool tip is improved by 6.72%. Amritaet al.[17] virtually explored the uses of Nano-graphite enhanced machining oil in turning process. They found the use of MQL with Nano-graphite fluid considerably reduced surface unevenness, cutting force, machining temperature and tool wear by 30%, 54%, 25% and 71%, respectively, compared with wet machining. Also, the comprehensive literature review has been done by Sharmaet al. [18] in which, the effect of MQL technique is compared with other machining operations for different Nano fluids and conventional cutting fluids.

Minimum Quantity Lubrication Application in Drilling Processes

Cutting fluid is vital in drilling as it is very helpful to remove the chips from inside the holes, thus preventing drill breakage. Some of the researchers have studied the use of MQL in studying the performance of various drill tool materials. Bragaet al. [19] have compared the performance of the uncoated and diamond coated carbide drills, using minimum quantity lubrication and abundant soluble oil as a coolant in the drilling of aluminium–silicon alloys (A356). They have found that the drill with diamond coat show poor performance as compared to uncoated K10 drill, because of chips sticking on the tool nose. It also generated greater feed force value. Heinemannet al. [20] concluded in their study that MQL implementing coolant with lofty water content and lower viscosity has a positive effect in deep-hole drilling as the coolant of low viscosity can enter the cutting zone easily as compared to highly viscous coolant. Tasdelen et al. [21] inspected the surface quality of holes, after drilling number of holes and established that MQL (15 millilitre per hour flow rate) drilling created even better drill holes in terms of Ra and Rz as compared to flood drilling technique.

Bhowmick and Alpas [22] in their research also agreed with these results finding. For drilling magnesium alloy, when we used MQL technique, it is found that less torque is required in collation with flood and dry drilling. Further the use of MQL results in reduction of temperature, which causes Mg adhesion to drill and built-up edge formation to be less.

The lowest percentage is showed with MQL – fatty acid cooling on drill tool surface area if it is surrounded by magnesium adhesion, compared to other conventional drilling processes. Rahim and Sasahara [23] performed experiments on Inconel metal 718 implementing palm oil and synthetic ester to study the effect of MQL on drilling process. They concluded that the use of MQL with palm oil shows improved surface finish when matched to MQL with synthetic ester. Also, the surface finish and tool life span improves using MQL when related to dry and wet drilling. Meena and Mansori [24] in their experimental studies found that flank wear of 0.12 mm for wet, 0.25 mm for MQL and 0.41 mm dry drilling.

Minimum Quantity Lubrication Application in Grinding

The MQL grinding provides improved machining outcomes with lower surface damage in comparison with dry and wet grinding. Various researchers in their experimental studies also found such type of results, which validates this statement. Shen et al. [25] analysed the grinding mechanism of MoS₂ nanoparticles based cutting liquid under MQL just as wet machining, and contrasted its execution and the outcomes got when utilizing ordinary oils (CANMIST, soybean and paraffin) under flood cooling. An improvement of 15%, 35% and 46% in the life span of grinding wheel and a recognizable decrease of 9%, 21% and 27% in grinding force could be accomplished by including MoS₂ nanoparticles in soybean oil, paraffin oil and CANMIST oil. Moreover, a high grinding ratio (G-ratio) was documented with high MoS₂ nanoparticles concentration utilizing MQL.

Mao et al.[26] saw that MQL delivered comparative outcomes to that of wet grinding regarding surface roughness, specific tangential and normal grinding forces. MQL diminished the temperature with tool forces and delivered practically identical (in some cases far superior) surface integrity than that of flood grinding. It is appropriate for ductile or soft metals. MQL has constraints with respect to difficult to cut materials (Barczak et al.) [27] For medium or high carbon steel like EN31, the temperature documented by flood lubrication was observed to be 20% lower than that with near dry machining while for low carbon steel, the temperature was like that in the flood lubrication with comparable explicit production rate. It also noticed lower temperature than wet machining with respect to EN8 steel. Thus, Morganet al.[28] observed MQL to be increasingly great for low carbon materials. Zhanget al. [29] studied experimentally the MoS₂ nanoparticles in jet MQL grinding with liquid paraffin, palm oil, rapeseed oil and soybean oil. They concluded that coefficient of friction for palm oil (0.37) is less than liquid paraffin (0.39) and Sp. Grinding Energy (U) for palm oil is higher as compared to other oils.

Minimum Quantity Lubrication Application in Milling Processes

The application of MQL can also be found in milling processes. For example, Garcia and Ribeiro[30] reported that MQL enabled better lubrication and cooling actions during end milling of Titanium Alloy. It was demonstrated by longer tool life and cutting force reduction. Moreover, Kang et al.[31] also emphasized the feasibility of MQL application even during higher cutting speed regimes. They found that the MQL application in cutting AISI D2 led to better machining performance compared to flood coolant, especially if appropriate cutting tools were selected. However, investigations were performed using constant cutting parameters and at defined MQL flow rate. Interestingly though, full implementation of the MQL application on the shop floor is in doubt due to the need for a cultural change. However, some companies, especially the large-scale manufacturing companies, have fully implemented this method to produce some parts. This implementation has shown some positive results for the future, as reported by Filipovic and Stephenson[32].

Brinksmeier et al.[33] conducted a milling process to cut TiAl6V4 material using a carbide K40 uncoated cutting tool. Constant machining variables used in this study were 210 m/min cutting speed, 0.08 mm/rev feed, 5 mm axial depth of cut and 2 mm radial depth of cut. After analysing the cutting forces, tool wear, surface quality and chip formation resulting from the study, they concluded that MQL application could provide comparable tool life travel compared to that of overhead flood cooling. This performance was obtained by using cutting fluid combined with 7% emulsion. Furthermore, it could be further enhanced by using phosphorus additives.

SUMMARY AND RECOMMENDATIONS FOR FUTURE RESEARCH

This paper has systematically reviewed the important published findings of research papers in the field of MQL technique for turning, drilling, milling and grinding processes. The machining processes presented in this work are: drilling, turning, milling and grinding. A pilot summary and techniques of the MQL system and its impact on output parameters in various machining processes, is likewise communicated in this paper. A large portion of the experimental studies demonstrated that MQL machining is a suitable choice to flood or wet machining, and which can encourage sustainable machining process.

CONCLUSIONS

The Subsequent opinions can be outlined to understand MQL technique and its uses later on research:

Application of minimum quantity lubrication (MQL) is favourable in situations, where dry machining application cannot be fully utilized due to limited capability of cutting tools. Hence, the optimum setting for MQL and machining variables can be used to improve the machining performance for the given work piece material. There was no agreement found in the literature, in respect of the range of cutting speeds that can be employed, so that the effectiveness of the MQL application can be expanded. It has been found that the absorption capability of workpiece materials play a vital role in the establishment of a protective film which would help the MQL application to perform at its best. Thus, it is conceivable that every workpiece material possesses its own characteristics when it is machined using the MQL application. Therefore, machining data for a wide variety of workpiece materials, used in machining processes using MQL, needs to be developed. Improving the MQL application may be essential to meet sustainable development criteria. This review revealed very little information on sustainability. Therefore, an environmental analysis has to be undertaken to assess the carbon footprint as well as the environmental burden, so that a clear position for the MQL application in respect of sustainable development, can be identified.

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